Geotrace TECHNOLOGIES

SCRIPPS / UNR

Survey: SONGS
Area: Offshore Southern California

2D High Resolution Processing
Final Report

Geotrace Project No.: 5800414

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Date: May 2014
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Seismic Data Processing Report

Area:	San Onofre Nuclear Generating Station (SONGS), Offshore Southern California
Date acquired:	August 2013 and December 2013
Date processed:	February – May 2014

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For:

Scripps University California San Diego
University Nevada Reno

Contents

Introduction

This report describes the 2D high resolution data processing carried out on behalf of Scripps UCSD and UNR during the period February 2014 to May 2014, by Geotrace Technologies.

The survey was acquired over the SONGS area, offshore southern California, USA. The data consisted of 3774.37 line kms of 2D seismic data. The first shipment of 2513.57 kms was acquired in August, 2013 and delivered on January 24, 2014. The second shipment of 1260.80 kms was acquired in December, 2013 and delivered on February 6, 2014.

Full details of the acquisition parameters can be found in Section 2 of this report and a full inventory of the lines processed is provided in the Appendix B.

This report covers the development and application of an appropriate data processing scheme, including the tests performed and a summary of the processing sequence adopted. The report also details the quality control products generated both as part of the processing QC.

The main objectives of the processing were to provide high quality imaging of shallow structures. Emphasis was placed on frequency preservation and multiple elimination.

The report concludes with a qualitative assessment of the project. Data and test examples are also included in the report.

Acquisition Parameters & Survey Area

Specifications

The survey was acquired by R/V New Horizon in August, 2013 and R/V New Melville in December, 2013 (Scripps Institute of Oceanography).

R/V New Horizon Acquisition Parameters, Sparker source

Number of sources	1
SP Interval	6.25 m
Depth of source	2.0 m
Power	2 KJ
Number of cables	1
Cable length	293.8 m
Cable depth	2.0 m
Number of groups	48
Group interval	6.25 m
Near offset	25.0 m
Nominal fold	24
Recording instrument	Geo-Eel
Recording format	SEG-Y (IBM)
Sample rate	0.5 ms
Data length	2000 ms
SODD	None

R/V New Horizon Acquisition Parameters, Boomer source

Number of sources	1
SP Interval	3.125 m
Depth of source	0.5 m
Power	1.5 KJ
Number of cables	1
Cable length	71.88 m
Cable depth	1.0 m
Number of groups	24
Group interval	3.125 m
Near offset	25.0 m
Nominal fold	12
Recording instrument	Geo-Eel
Recording format	SEG-Y (IBM)
Sample rate	0.25 ms
Data length	500 ms*
SODD	None

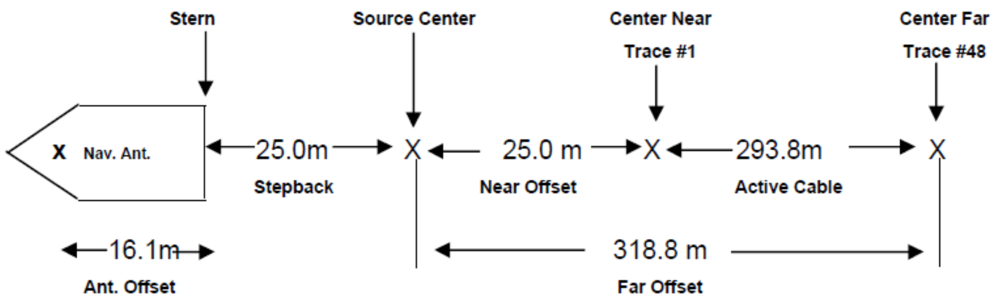
*Data Length varied for 3 lines: 12C – 1000ms, 12D – 1500ms, 160-700ms

R/V New Melville Acquisition Parameters, Sparker source

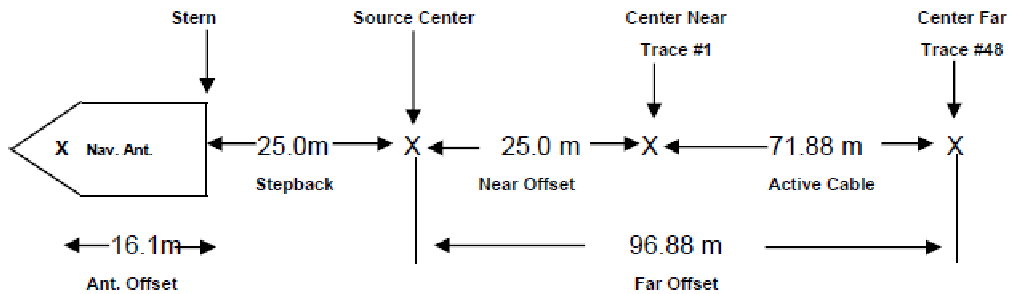
Number of sources	1
SP Interval	3 sec (approximately 6.25 m)
Depth of source	3.0 m
Power	2 KJ
Number of cables	1
Cable length	293.8 m
Cable depth	3.0 m
Number of groups	48
Group interval	6.25 m
Near offset	25.0 m
Nominal fold	24
Recording instrument	Geo-Eel
Recording format	SEG-Y (IBM)
Sample rate	0.5 ms
Data length	2500 ms
SODD	None

Boat Diagrams

Sparker Configuration



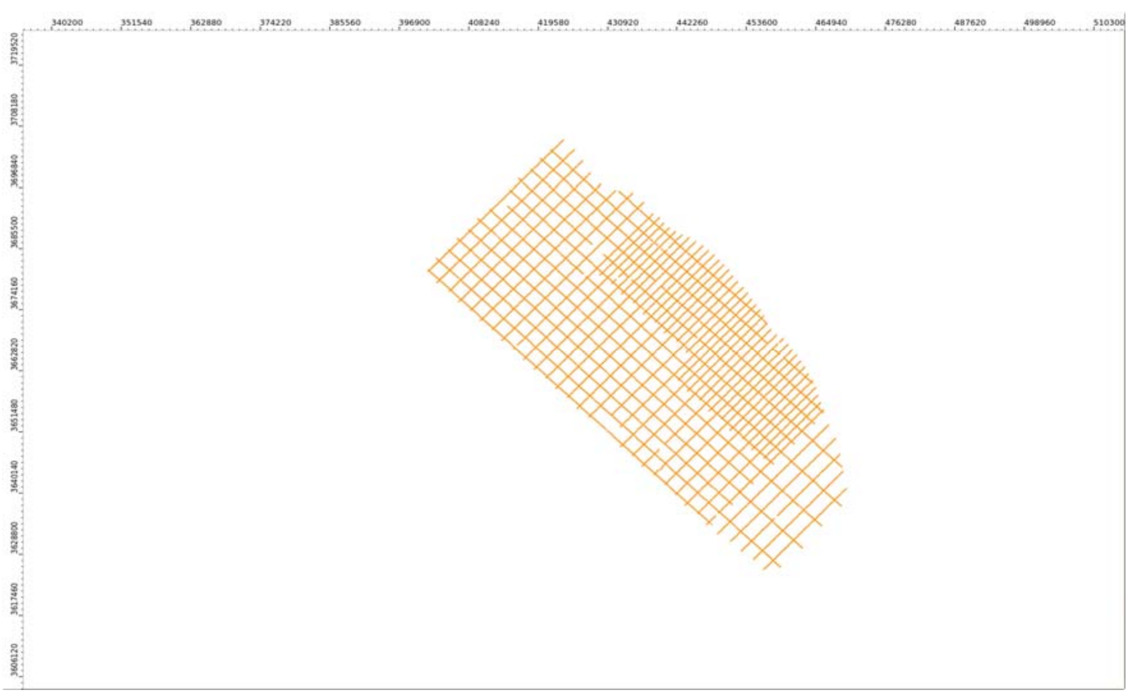
Boomer Configuration



Survey Area

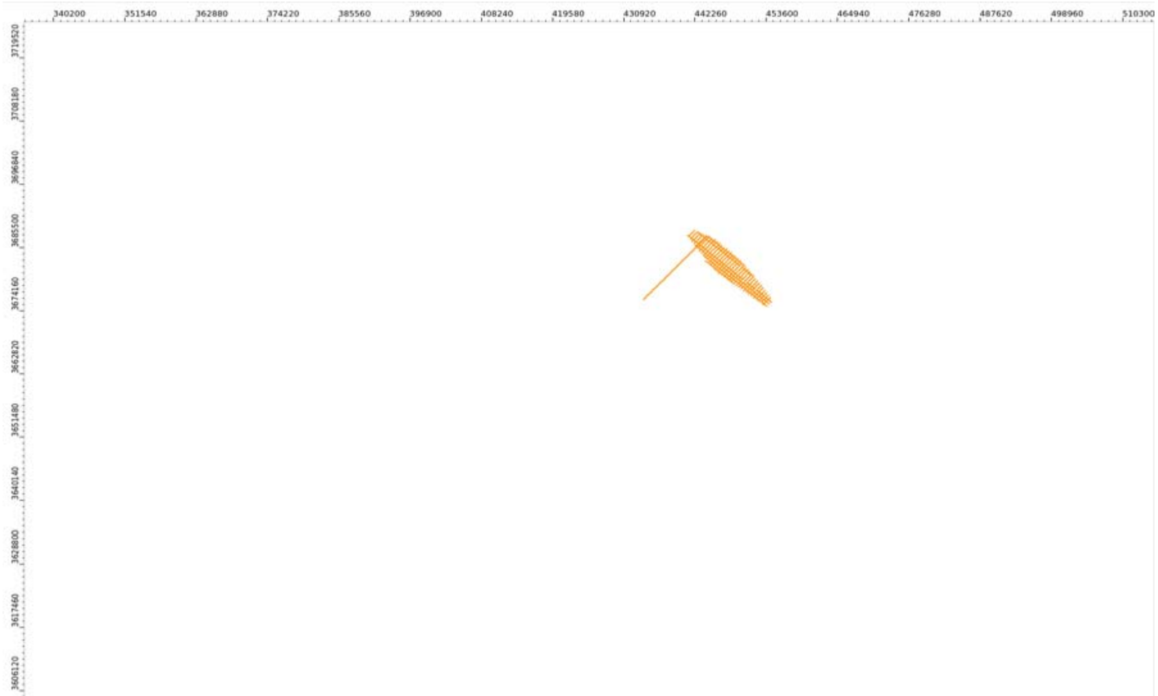
Sparker Shot Map (R/V New Horizon)

(as acquired source positions)



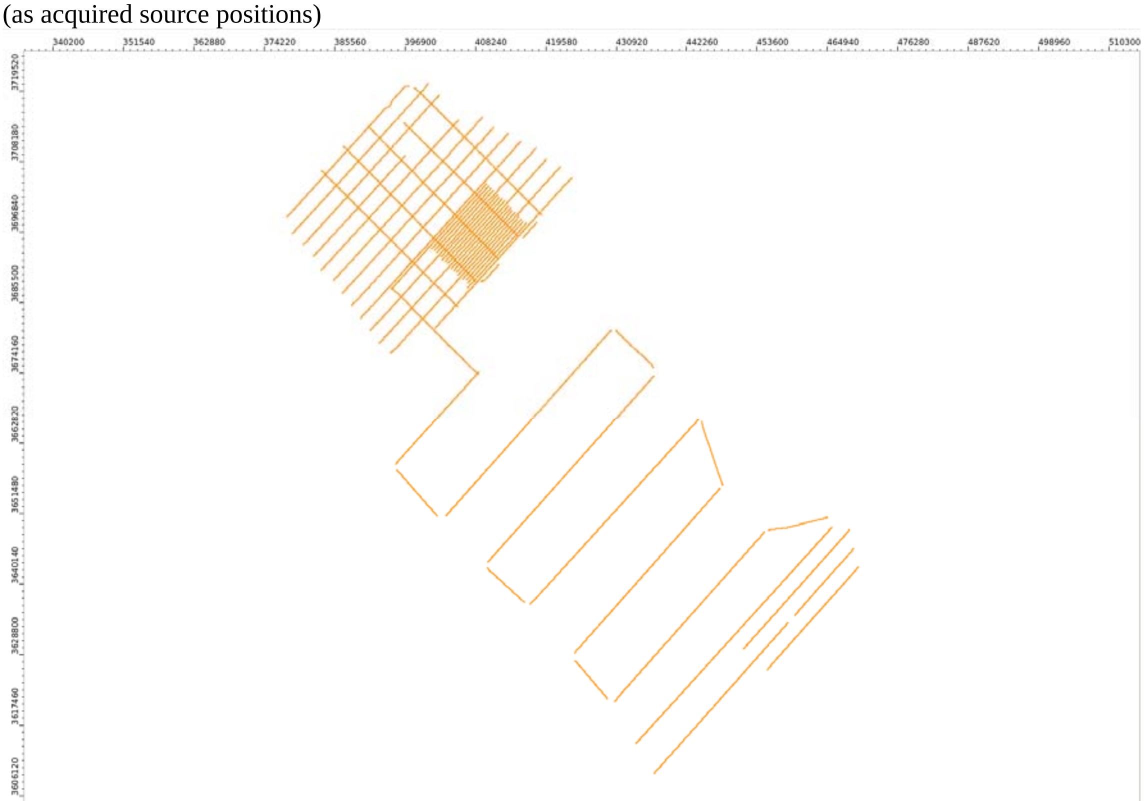
Boomer Shot Map

(as acquired source positions)

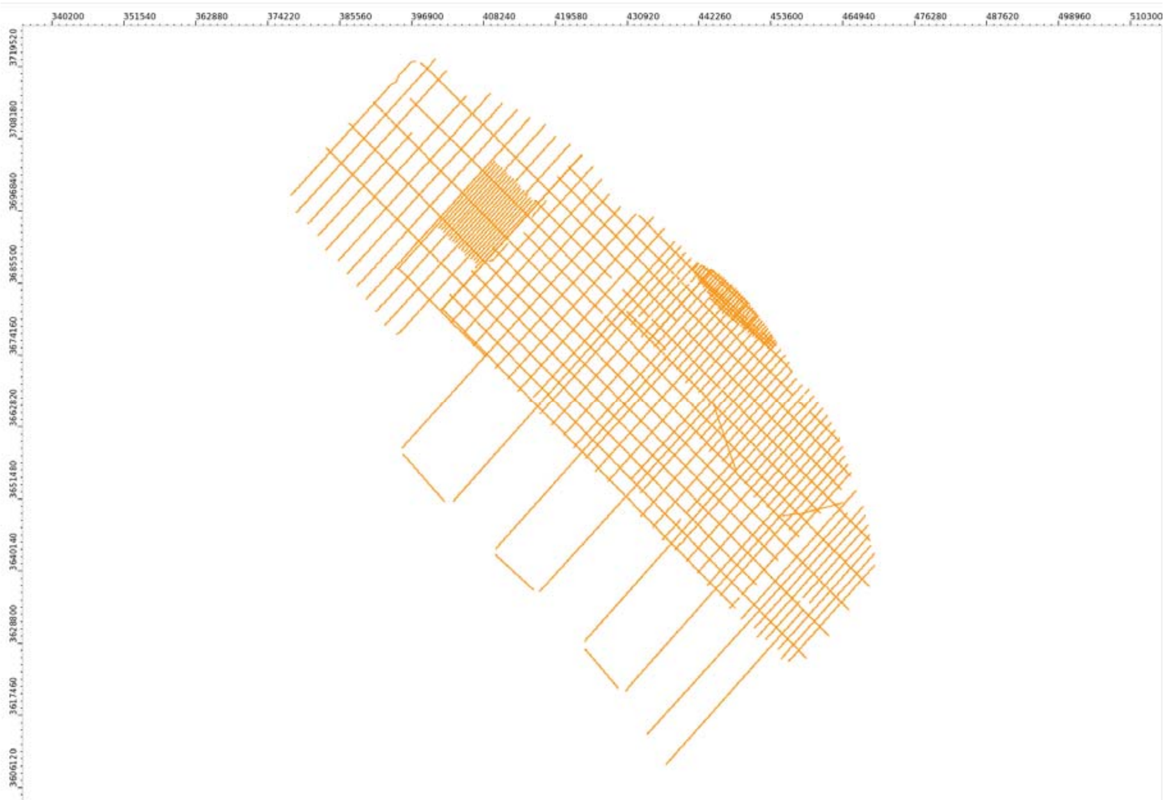


Sparker Shot Map (R/V New Melville)

(as acquired source positions)



Combined surveys
(as acquired source positions)



Navigation & 3D Geometry Definition

Coordinate System

Processed navigation data in UKOOA P1/90 format was supplied for the Boomer and Sparker data acquired by R/V New Horizon:-

Geodetic Datum:	WGS84
Spheroid:	WGS84
Longitude of Central Meridian:	117° West
Projection Type:	001 UTM North
UTM Projection Zone:	11 N

Processed navigation was not supplied for the Sparker data acquired by R/V Melville. Navigation coordinates were applied to the supplied data.

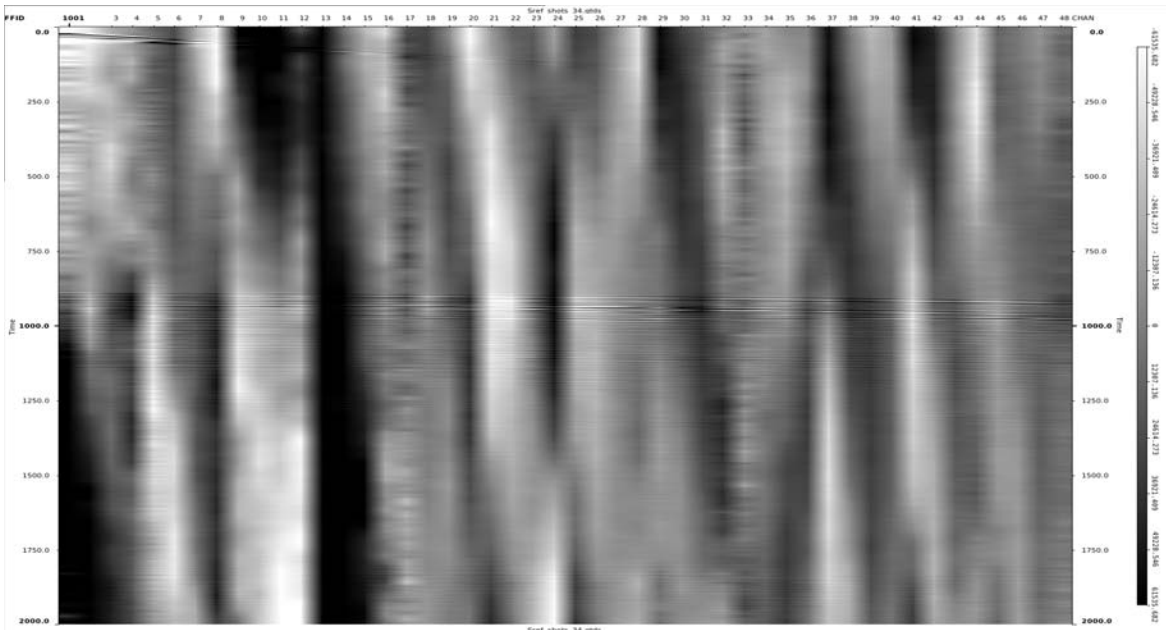
Processing Flow

1. Seg-y Reformat
2. Low cut filter
3. Resample to 1ms with anti-alias filter
4. Bad Trace Edits
5. Automatic spike removal
6. 2D SRME multiple removal
7. X-T deconvolution
8. Preliminary velocity analysis and intrepretation (500m grid)
9. FDNA (frequency domain noise attenuation)
10. Pre-Stack Kirchhoff migration
11. ‘Flatrem’ multiple removal
12. Final Stack
13. X-T deconvolution
14. FXY Deconvolution
15. Time Variant Filter
16. Amplitude balancing by measured exponential gain
17. Gun and Cable static
18. Survey matching to 3D P-cable data
19. SEGY

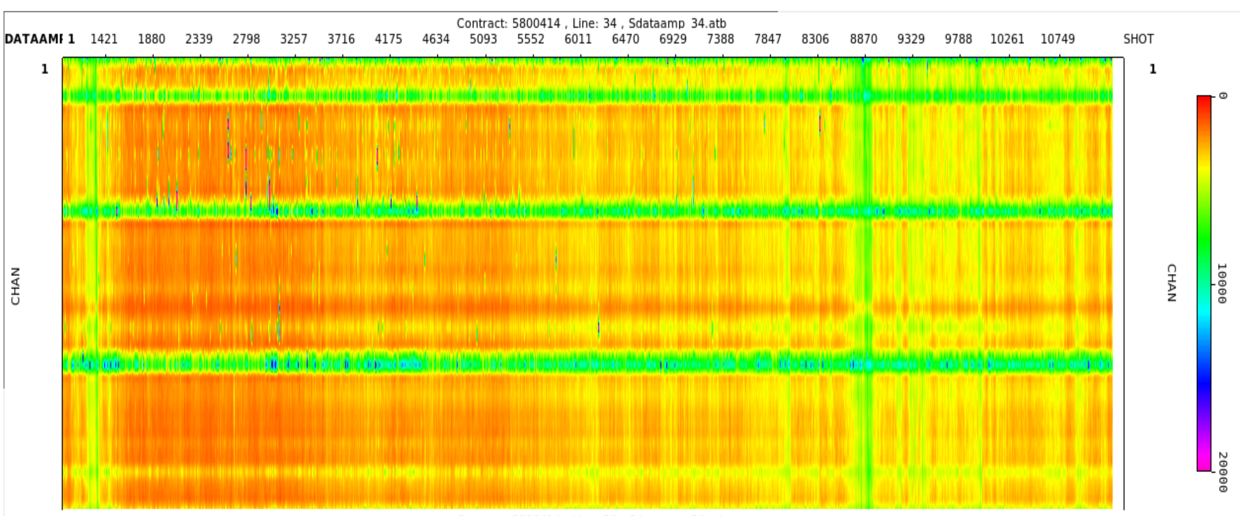
Preliminary Processing

SEGY Reformat and QC examples

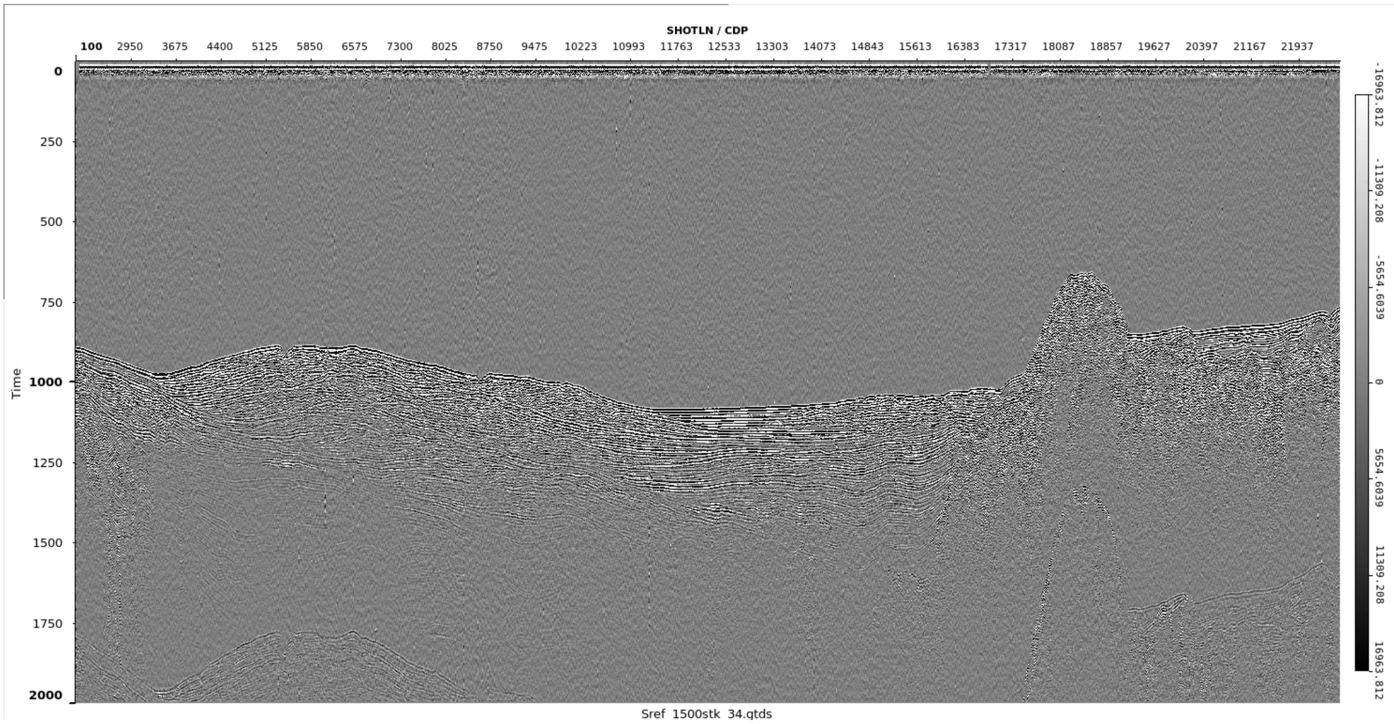
Data was reformatted from SEGY to Geotrace format.



Example of a raw shot from line 34.

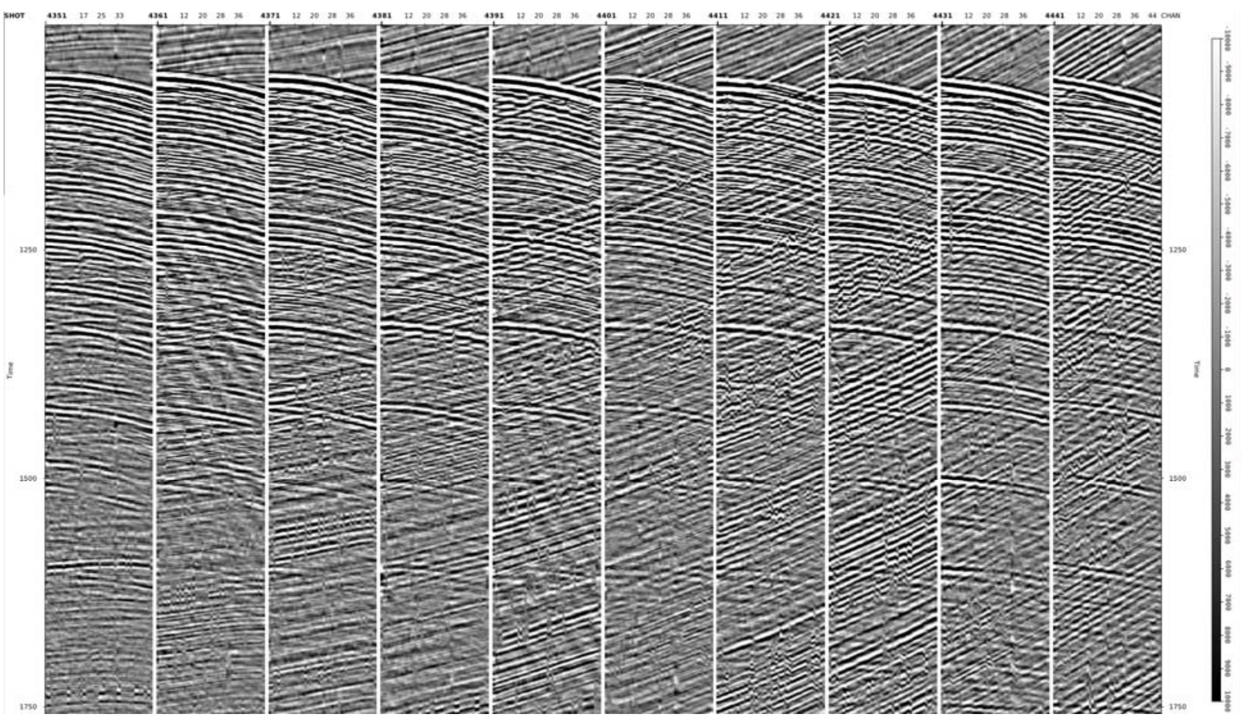


Example of a data window amplitude map from line 34.

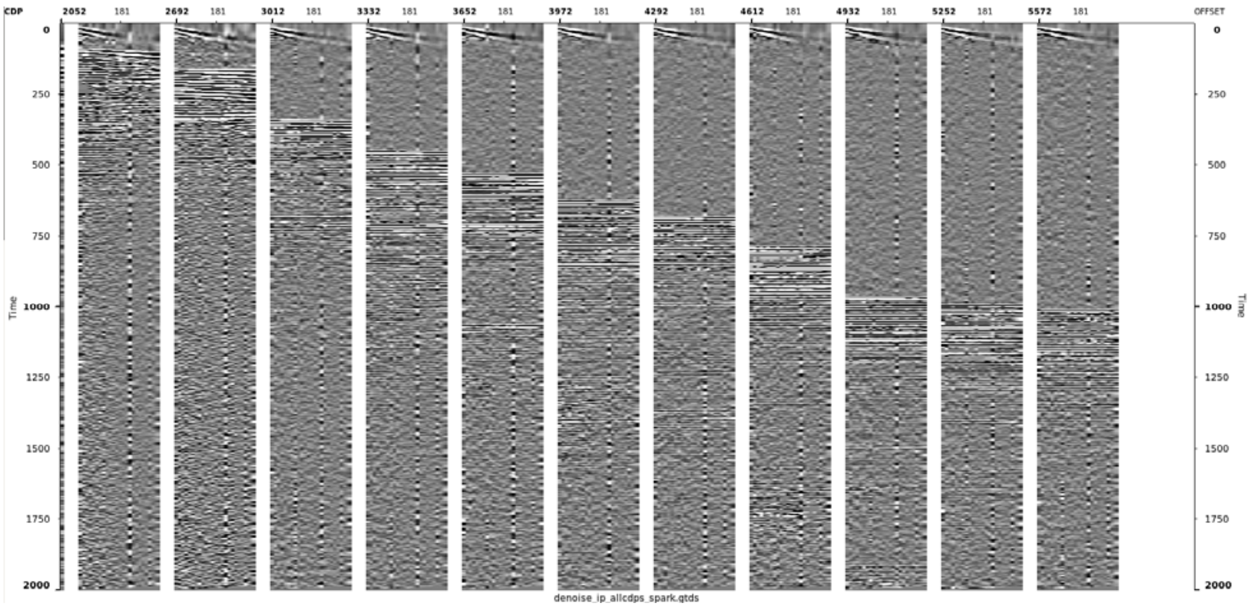


Example of a brute stack from line 34.

<u>Noise Examples</u>

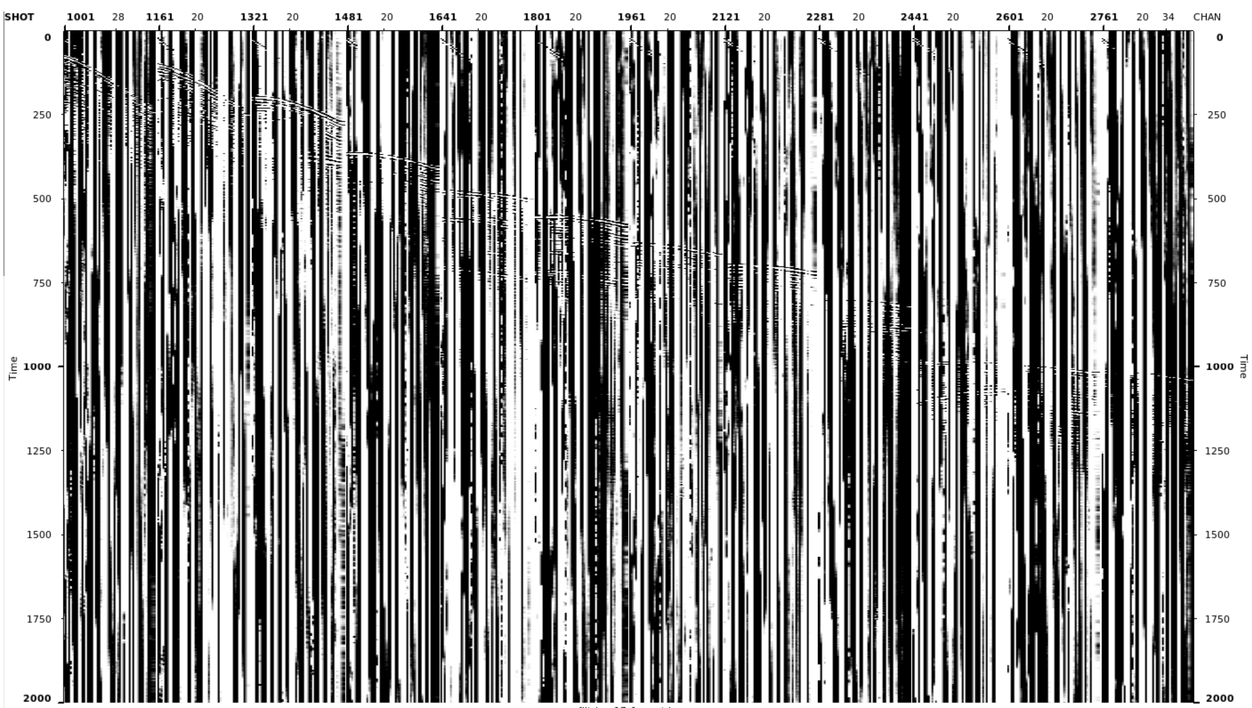


Example shots with seismic interference (SI).

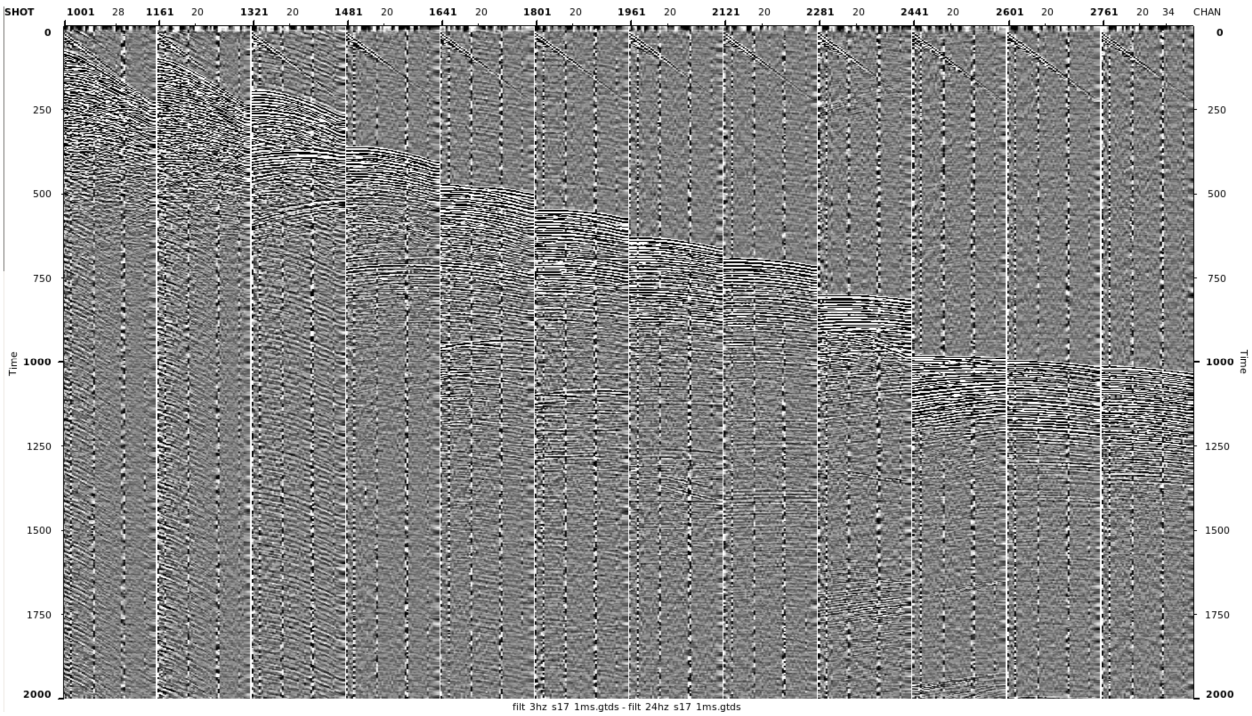


Example cdps with spikes/noisy traces.

Low Cut Filter Application



Example of supplied shots.



Example of supplied shots with 24Hz low cut filter applied.

Designature / Debubble

No far field was available for the source used in the acquisition. Therefore no designature or debubble was applied in the final processing with the data being left at acquired or minimum phase.

Temporal resample

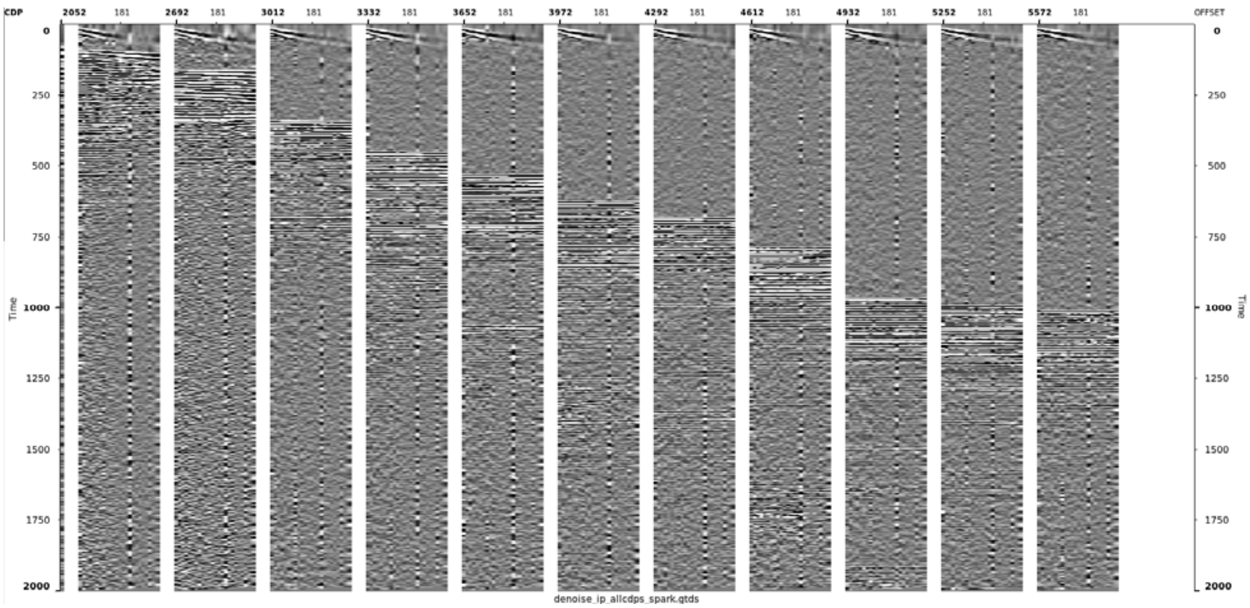
A 375(96) Hz (dB/Octave) anti-alias minimum phase filter was applied prior to resampling from 0.25ms (or 0.5ms) to 1ms.

Bad trace editing

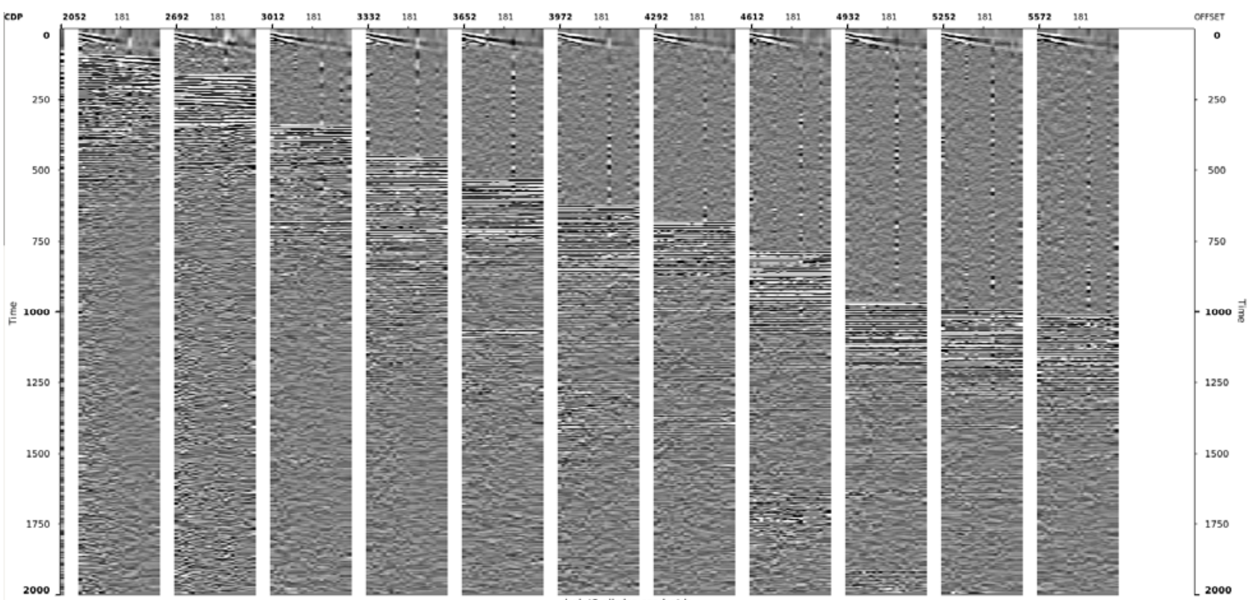
Geotrace confirmed the single trace edits flagged during the reformat QC.

Noise Attenuation

A spike removal process was tested and found to be effective. The program locates high amplitude spikes and noise bursts within seismic data and replaces the affected samples with data averaged from the surrounding traces. Spikes are found by comparing the ratio between the each sample amplitude on the input trace to the RMS average. Whenever the ratio exceeds a given threshold level, that input sample is defined as a spike. The spike definition can be extended to a user-specified number of samples in time before and after the current sample. For each input trace the program sums together a number of adjacent traces to form a reference trace (after first squaring their values). The reference trace is smoothed over a time gate by applying a running average. After normalization and application of a square root, the sample values stored in the reference trace form the 2-dimensional window averages to be used in the comparisons. Amplitude de-spiking was applied in the shot domain.



Example cdps before spike removal.



Example cdps after spike removal.

Pre-migration Processing

Surface Related Multiple Elimination (SRME)

Surface Related Multiple Elimination was applied to coincident shots and receivers each 6.25m apart. SRME is a pre-stack technique designed to attenuate surface generated multiples following studies made by Verschuur et. al. and described in a number of publications including the Journal of Seismic

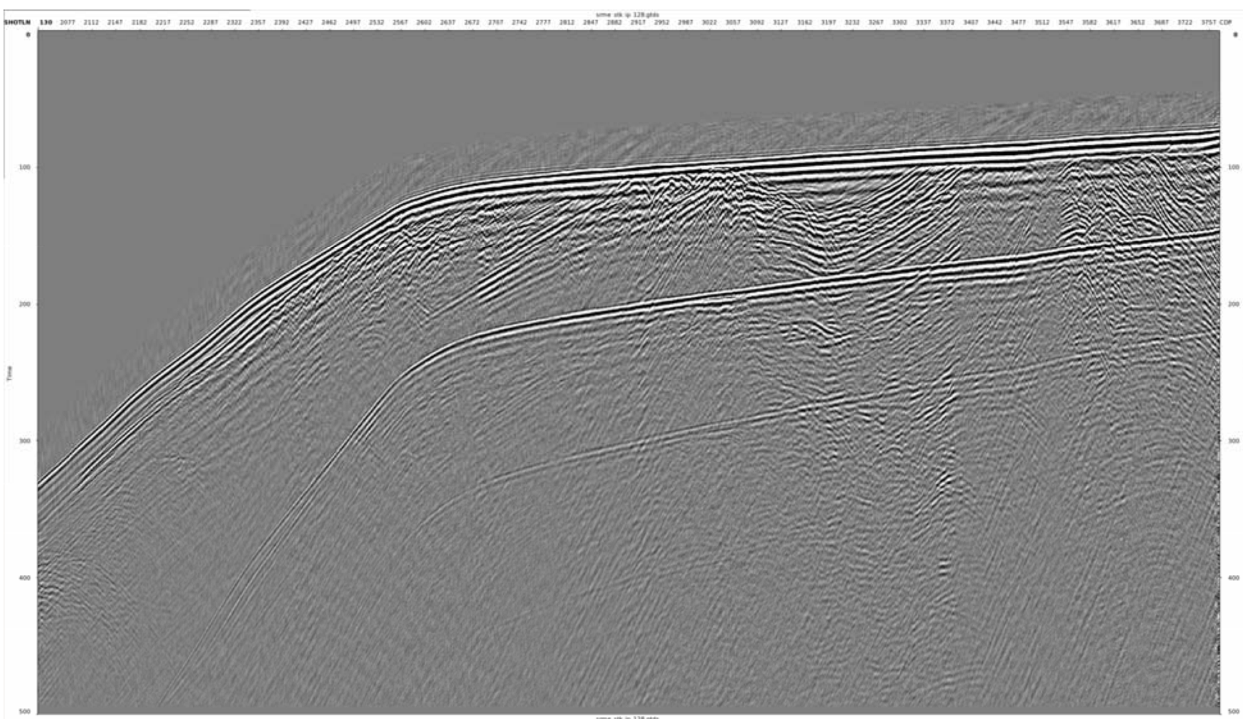
Exploration, 1, Jan. 1992. The method utilises the general wave equation boundary condition and makes no assumptions regarding wave behaviour in the earth. No prior model or knowledge of the sub-surface is therefore necessary.

In addition, traces were extrapolated to zero offset within the shot records.

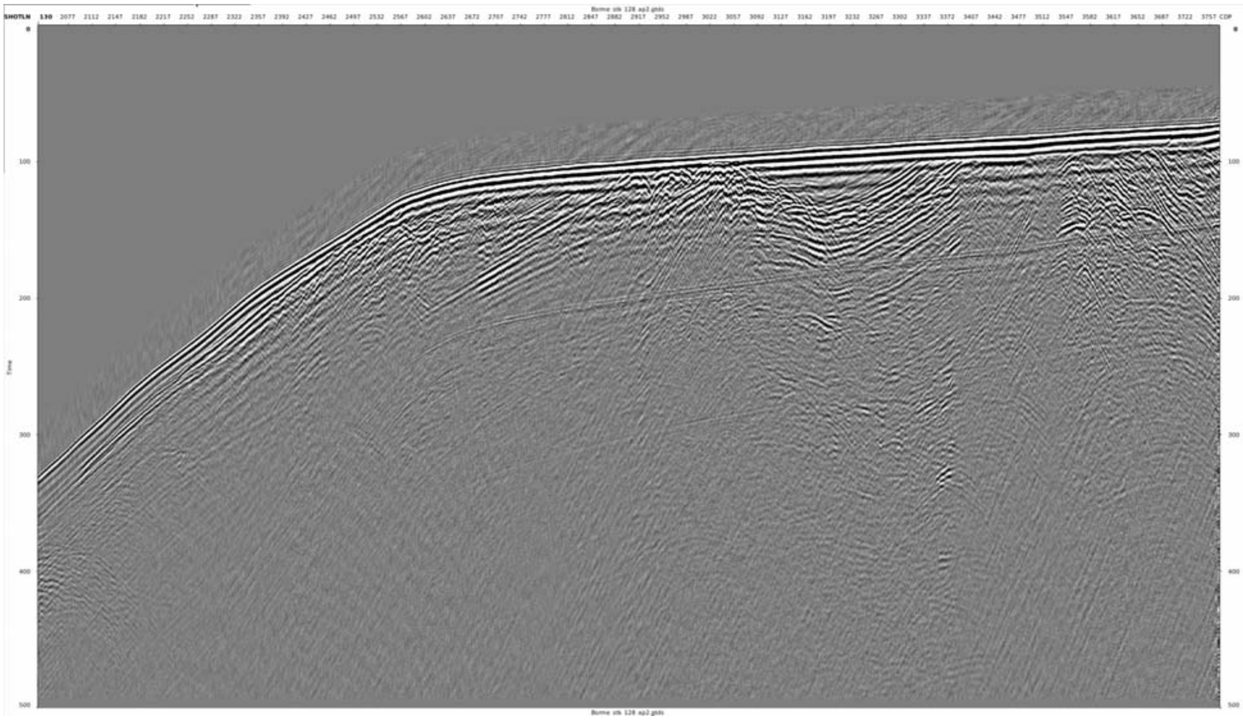
Three iterations of SRME were performed on the data. A multiple estimate is made and subtracted from the input data. Both the results of this subtraction and the unchanged input data are passed on for further processing. Subsequent iterations use the result of the previous subtraction as input to the multiple prediction. After the final iteration, the final multiple estimate is adaptively subtracted from the original input data.

The adaptive subtraction was performed within common channel records. The multiple model was matched and subtracted as follows:

i) Match the gross amplitude difference between the input data and the multiple model. This is designed on the whole record and applied as a single point filter.
ii) Filter to match the phase.
iii) Filter to match the amplitudes.



Example input brute stack before SRME.



Example input brute stack after SRME application.

X-T Deconvolution

Due to the depth of the water bottom the data was suitable for decovolution. A water bottom gap (predictive) deconvolution before stack (DBS) was tested and found to be successful at removing multiple energy evident in the CDPs.

Various operator lengths and gaps were tested and displayed with stacks. The chosen one window deconvolution was applied in the space-time (X-T) domain.

Water bottom gap deconvolution was tested and confirmed for production using the following parameters:-

Minimum Prediction Lag 12 ms
Maximum Prediction Lag 24 ms

Boomer
Design windows 1
Near trace 50 ms – 500 ms
Far trace 50 ms – 500 ms
Application windows 1
Near trace 100 ms – 500 ms
Far trace 100 ms – 500 ms

Sparker
Design windows 1
Near trace 950 ms – 1600 ms

	Far trace 950 ms – 1600 ms	
Application windows	1	
	Near trace 1000 ms – 3000 ms	
	Far trace 1000 ms – 3000 ms	

Velocity Analysis

The preliminary velocity analysis was performed on each 2D sail line every 500m. Velocity interpretation was done using the Geotrace Diamond Velocity WorkBench (VWB) workstation. CDP gathers, semblance plots, variable velocity stacks and brute velocity stack were generated to aid in the velocity interpretation.

FDNA Noise Attenuation

Following the velocity analysis and intrepretation, Frequency Dependent Noise Attenuation (FDNA) was tested in an attempt to prevent unwanted migration artifacts during the imaging step.

FDNA (frequency domain noise attenuation) focuses more on any high frequency remnant noise remaining after stack. At the high frequency level, it can be used effectively to attenuate diffracted noise such as multiples based on discrimination of frequency content between primary and non-primary events.

FDNA operates on one ensemble at a time. Each ensemble is transformed into time-frequency space using a short time Fourier transform algorithm. The transform is separated into amplitude and phase components for each frequency sub-band. If auto-thresholding is requested then the median spectral amplitude within each requested frequency sub-band is calculated for the ensemble.

The median of these medians becomes the threshold for that ensemble. Each sample of each requested sub-band is compared against this threshold. If the sample amplitude exceeds the threshold then the median spectral amplitude of the adjacent samples within that sub-band is computed and installed at this location.

Boomer data

Number traces		5 (rolling window)
Threshold		4 x the median value
Frequency bandwidth* attacked		20-250 Hz
Start-time	Near offset	150ms (contoured to water bottom time)
	Far offset	155ms

Sparker data

Number traces		5 (rolling window)
Threshold		4 x the median value
Frequency bandwidth* attacked		20-250 Hz

Start-time	Near offset	200ms (contoured to water bottom time)
	Far offset	125ms

Kirchhoff, pre stack time migration

A pre stack Kirchhoff algorithm was used to migrate the data. A series of impulse responses were performed initially to establish suitable migration parameters.

An aperture of 1 km with a dip limit of 85° was selected for the final migration for Sparker. For the Boomer survey there was a time variant aperture of 50m at 50ms, at 90m at 250ms, and 100m at 500ms. Boomer had a dip limit of 45°.

Post Migration Processing

Final Stack

The final data were stacked and 1/N normalisation was applied where N is the number of live samples stacked.

‘Flatrem’ Multiple Removal

A version of Geotrace’s TASER™ (Targeted Apex Shifted Elimination Routine) was used to further attenuate the first bounce of the water bottom multiple by applying a pre-stack dip filter to a select range of near trace offsets.

The data was first sorted into offset planes with NMO correction applied. The data then was statically corrected so that the first waster bottom multiple was at a constant time. A targeted FK dip filter isolates the subsequently flat multiple energy. Because of the static correction the water bottom multiple is flat at this time and is therefore removed (Flat Remove or ‘Flatrem’).

By randomizing the data we are able to preserve primary events while effectively removing the multiple. This sequence is only applied to the first 6 offset planes covering 61m of offset for the Boomer data and 12 offset planes covering 169m of offset for the Sparker data. Data was then sorted back into CDP domain.

X-T Deconvolution

A water bottom gap (predictive) deconvolution after stack (DAS) was tested and found to be successful at removing remnant interbed multiples just below the waterbottom.

Water bottom gap deconvolution was tested and confirmed for production using the following parameters:-

Boomer

Minimum Prediction Lag		14 ms
Maximum Prediction Lag		120 ms
Design windows		1
	Near trace	40 ms – 300 ms (contoured to waterbottom time)
	Far trace	40 ms – 400 ms
Application windows		1
	Near trace	40 ms – 500 ms (contoured to waterbottom time)
	Far trace	40 ms – 500 ms

Sparker

Minimum Prediction Lag		24 ms
Maximum Prediction Lag		480 ms
Design windows		1
	Near trace	40 ms – 350 ms (contoured to waterbottom time)
	Far trace	1180 ms – 1450 ms
Application windows		1
	Near trace	40 ms – 2000 ms (contoured to waterbottom time)
	Far trace	1180 ms – 2000 ms

FXY Deconvolution

FXY was also tested to attenuate any pure random noise throughout the section.

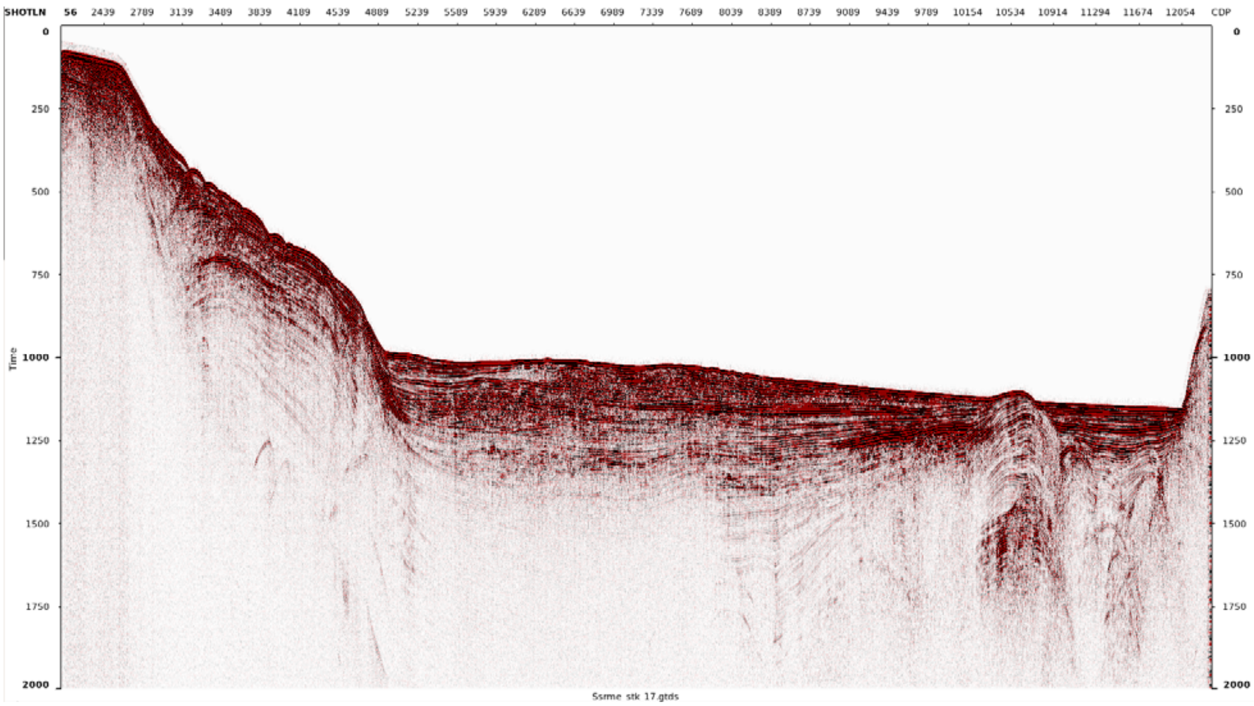
Within a 2D stack (line), flat events appear as complex sinusoidal oscillations in the F-X domain. By designing and applying complex one-step-ahead predictive operators within a sliding trace gate, the sinusoidal oscillations may be separated from the random noise which contaminates them. The width of the trace gate is selected such that curved data appear locally linear.

In 3D, the linear model is extended to include locally planar surfaces. The spatial distribution of the F-X-Y filter coefficients provides for better preservation of low amplitude events and curved surfaces than either 2D or two-pass approaches.

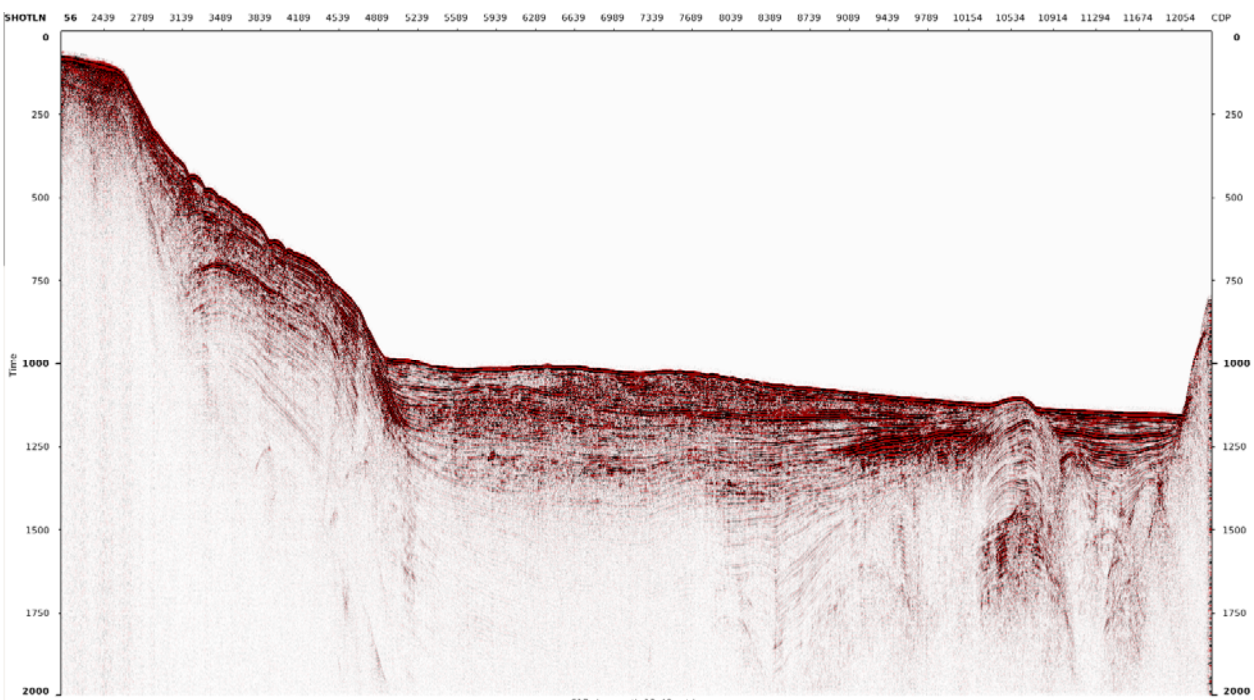
Boomer and Sparker data

Frequencies	1-500 Hz
Iterations	1
White noise	0%
Gate Overlap	33% each in line, cdp, and time directions

Filter design widths	5 traces in both line and cdp directions
Autocorrelation Window lengths	41 traces in both line and cdp directions



Example input brute stack Sparker line 17.



Example brute stack after FXY Deconvolution application.

Time Variant Filter

A post stack time variant filter was applied based upon a start time header which varied spatially depending upon the water depth along each line. Filtering the high frequency noise in the deepest sections of the lines enhanced the stack response of the lower frequency primary events. The filter applied was defined as follows:

Boomer data

Water bottom time=70ms:

Time(ms)	Low Cut (dB/Oct.)	High Cut (dB/Oct.)
100	24 (72)	480 (72)
250	24 (72)	400 (72)
500	24 (72)	360 (72)

Water bottom time=300ms:

Time(ms)	Low Cut (dB/Oct.)	High Cut (dB/Oct.)
310	24 (72)	480 (72)
420	24 (72)	440 (72)
500	24 (72)	400 (72)

Sparker data

Water bottom time=100ms:

Time(ms)	Low Cut (dB/Oct.)	High Cut (dB/Oct.)
100	24 (36)	480 (36)
510	24 (36)	360 (36)
1010	24 (36)	240 (36)
2000	24 (36)	200 (36)

Water bottom time=1200ms:

Time(ms)	Low Cut (dB/Oct.)	High Cut (dB/Oct.)
1200	24 (36)	480 (36)
1510	24 (36)	440 (36)
1810	24 (36)	410 (36)
2000	24 (36)	360 (36)

Amplitude Balancing by Measured Exponential Gain

The final migrated section was balanced by the application of a measured exponential gain.

Boomer data

Water bottom time=50ms:

Time (ms)	Gain (dBs)
50	0
60	10
250	11
450	12

Water bottom time=100ms:

Time (ms)	Gain (dBs)
100	0
125	10
350	11
450	12

Water bottom time=250ms:

Time (ms)	Gain (dBs)
250	0
275	10
350	11
450	12

Sparker data

Water bottom time=50ms:

Time (ms)	Gain (dBs)
45	0
500	4
1000	12
2000	20

Water bottom time=600ms:

Time (ms)	Gain (dBs)
550	0
1100	4
1600	18
2000	26

Water bottom time=1100ms:

Time (ms)	Gain (dBs)
1000	0
1300	0

1500	6
2000	18

Gun and cable static

A correction for the source and receiver depths was made applying a +1 ms bulk shift to all Boomer data and +3 ms bulk shift to all Sparker data.

Survey Matching to 3D P-cable data

The 2D Boomer and Sparker data matching to the 3D P-cable Boomer and Sparker surveys involved analyzing the amplitude, frequency, timing, and phase differences as individual elements in order to establish single global filters and scalars if needed.

In all cases, diagnostics were run from traces at identical spatial locations in the surveys. The windows chosen for the matching were designed with signal to noise considerations in mind.

Average amplitudes were measured for the full trace length in 50ms windows on the surveys and compared. A global scalar and a time variant gain so derived was applied to both Boomer and Sparker data in order to correct the gain function to that of the 3D P-cable or 'base' surveys.

Final Products

Description	Output Medium	Number of copies
Final PSTM Migrated Stack	SEG-Y format on USB disk	2
Final PSTM Migrated CDPs	SEG-Y format on USB disk	2
Final Stacking Velocities	SEG-Y format on USB disk	2
Final Report	Digital	1

Conclusion

The 2D processing flow was developed alongside and following the processing of the 3D P-cable Boomer and Sparker surveys along with extensive and thorough testing. Geotrace employed various methods of noise and multiple attenuation in order to deliver a high quality product.

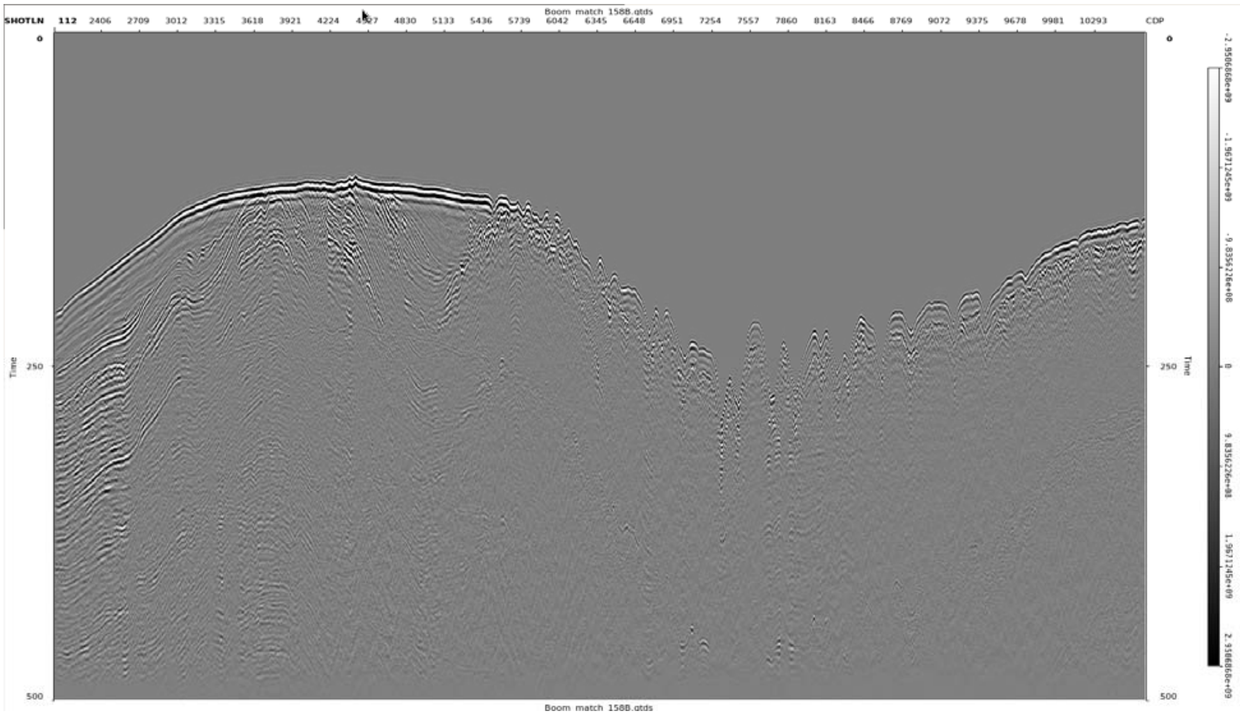
Being able to design the 2D processing flow at roughly the same time as the 3D surveys gave further evidence which supported the parameters selected for both the P-cable 3D surveys and the 2D data were in fact correct.

The 2D lines also provided an additional offset range and fold of coverage which the P-cable 3D surveys lacked. These extra offsets and fold allowed for testing and use of more pre-stack, multi-channel processes such as velocity analysis and interpretation, deconvolution before stack (DBS), and 'Flatrem'.

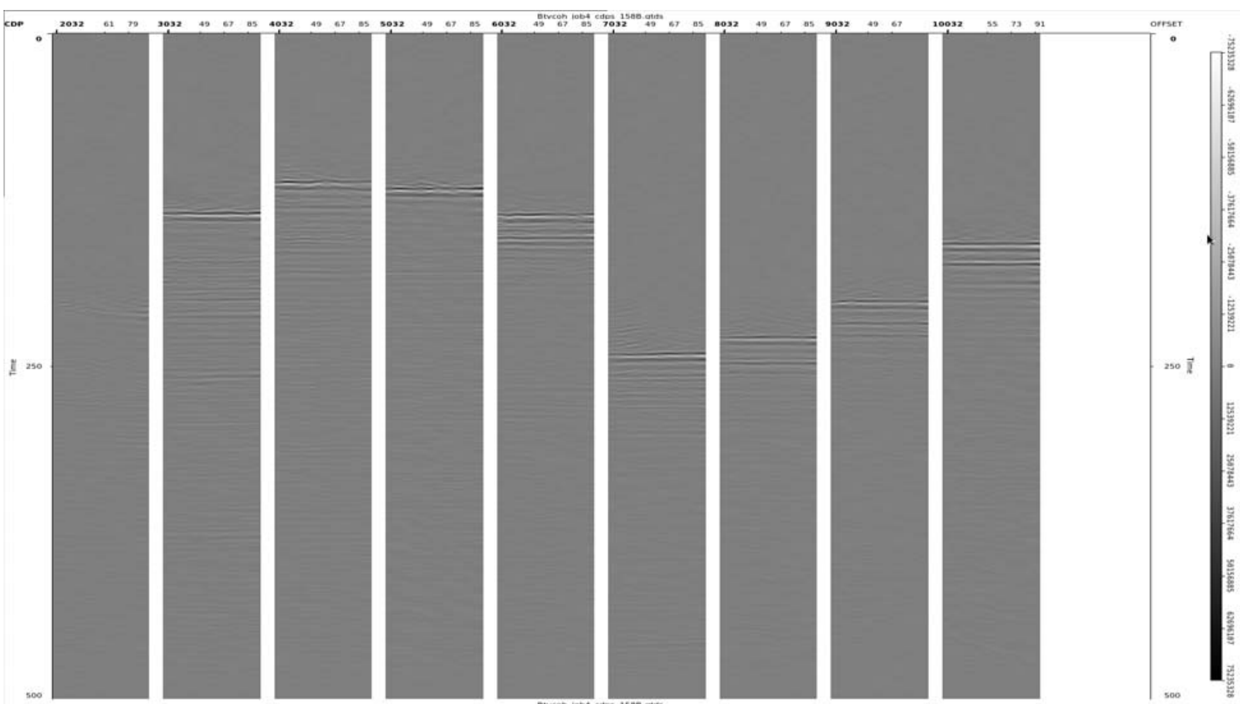
The use of known velocities from the 2D processing aided not only this project but also provided the basis for developing the 3D velocity model used in the 3D P-cable PSDM products.

Good communications were maintained with Scripps/UNR throughout the project through email and weekly reports.

Appendix A - Example Seismic Section



Boomer Line 158B Final Stack.



Boomer Line 158B Migration CDPs Example.

Appendix B – Sail-line Listing

Line Name	Sequence Number	Source Used
1	83	Sparker
2	82	Sparker
3	81	Sparker
4	80	Sparker
5	78	Sparker
6	77	Sparker
7	76	Sparker
8	75	Sparker
9	74	Sparker
10	72	Sparker
11	44	Sparker
12	45	Sparker
12C	162	Sparker
12D		
13	47	Sparker
14	48	Sparker
15	49	Sparker
16	50	Sparker
17	56	Sparker
18	57	Sparker
19	58	Sparker
20	59	Sparker
21	60	Sparker
22	62	Sparker
23	63	Sparker
24	64	Sparker
25	65	Sparker
26	66	Sparker
27	67	Sparker
28	85	Sparker
29	86	Sparker
30	92	Sparker
31	93	Sparker
32	95	Sparker
33	99	Sparker

34	100	Sparker
35	102	Sparker
36	103	Sparker
36B		Sparker
37	104	Sparker
38	105	Sparker
39	107	Sparker
40	108	Sparker
41	109	Sparker
50	163	Sparker
51	164	Sparker
52	165	Sparker
53	168	Sparker
54	169	Sparker
55	170	Sparker
56	171	Sparker
57	172	Sparker
58	173	Sparker
59	174	Sparker
60	175	Sparker
61	176	Sparker
62	177	Sparker
63	179	Sparker
64B	181	Sparker
65	182	Sparker
66	183	Sparker
67	184	Sparker
68	84	Sparker
161	185	Sparker
162	186	Sparker
163	187	Sparker
164	189	Sparker
165	190	Sparker
166	196	Sparker
167	195	Sparker
168	194	Sparker
169	192	Sparker
170	191	Sparker
158B	112	Boomer
156	113	Boomer
154	114	Boomer
152	118	Boomer

150	119	Boomer
148	11	Boomer
146	122	Boomer
142	123	Boomer
140	124	Boomer
138	125	Boomer
136	126	Boomer
134	127	Boomer
132	128	Boomer
130	129	Boomer
128	130	Boomer
126	131	Boomer
124	132	Boomer
122	133	Boomer
120	134	Boomer
118	135	Boomer
116	136	Boomer
114	137	Boomer
112	138	Boomer
110	139	Boomer
108	140	Boomer
106	141	Boomer
104	142	Boomer
102	144	Boomer
100	145	Boomer
98	146	Boomer
96	147	Boomer
94	148	Boomer
92B	150	Boomer
90	151	Boomer
88	152	Boomer
86	153	Boomer
84	154	Boomer
82	155	Boomer
80	156	Boomer
78	157	Boomer
76	158	Boomer
74	159	Boomer
104C	160	Boomer
12C	161	Boomer
12D	161	Boomer
160	110	Boomer

FS01		Sparker
FS02		Sparker
FS03		Sparker
FS04		Sparker
FS05		Sparker
FS06		Sparker
FS07		Sparker
FS08		Sparker
FS09		Sparker
FS10		Sparker
FS11		Sparker
FS12		Sparker
FS13		Sparker
FS14		Sparker
FS15		Sparker
FS16		Sparker
LJ01		Sparker
LJ02		Sparker
LJ02B		Sparker
LJ03		Sparker
LJ04		Sparker
N01		Sparker
N02		Sparker
N03		Sparker
N04		Sparker
N05		Sparker
N06		Sparker
N07		Sparker
N08		Sparker
N09		Sparker
N09B		Sparker
N10		Sparker
N11		Sparker
N12		Sparker
N13		Sparker
N14		Sparker
N15		Sparker
N16		Sparker
N17		Sparker
N18		Sparker
N20		Sparker
RS01		Sparker

RS02		Sparker
RS03		Sparker
RS04		Sparker
RS05		Sparker
RS06		Sparker
RS07		Sparker
RS08		Sparker
RS09		Sparker
RS10		Sparker
RS11		Sparker
RS12		Sparker
TR1		Sparker
TR2		Sparker